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Opportunities to Use Coal in Enhanced Oil Recovery

A project supported in part by the Alberta/Canada
Energy Resources Research Fund

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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of our resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal and conventional energy resources, as well as energy conservation and renewable energy. Program administration is provided by staff within the Scientific and Engineering Services and Research Division of Alberta Energy.

In recognition of the importance of coal to Alberta's economy, the Alberta Office of Coal Research and Technology was established in 1984 within Alberta Energy and Natural Resources (now Alberta Energy). Its primary purpose is to encourage the development and application of new technologies related to Alberta coals. The Office provides funding contributions to research and development projects in industry, academic institutions and other research establishments and monitors their progress in an overall program of improving the production, transportation and marketability of Alberta coals.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page eight.

Opportunities to Use Coal in Enhanced Oil Recovery

Approximately 47 per cent of the world's reserves of oil sands and heavy oil are found in Canada, mostly in Alberta.

These reserves, which occur in four deposits in eastern and north-central Alberta, are referred to as: Athabasca-Wabasca, Peace River, Cold Lake and Lloydminster. The latter deposit extends from Alberta into western Saskatchewan.

The latest estimates of the amount of petroleum remaining in these reserves, as compiled by Alberta's Energy Resources Conservation Board (ERCB), indicate that the energy contained in oil sands and heavy oil is up to six times that available from Alberta's known reserves of conventional oil. Therefore, there is considerable interest in extracting as much petroleum as possible from these deposits, but this undoubtedly will require the use of enhanced oil recovery methods.

Oil sand, or bitumen, a thick, tar-like substance, is found in seams up to 60 m (200 ft.) thick, buried beneath an overburden of surface soil as deep as 800 m (2 600 ft.). Heavy oil, which is a thick, sticky, viscous form of oil with a high sulphur and asphalt content, is found in sandstone formations generally 3 to 6 m (10 to 20 ft.) thick at depths between 300 and 900 m (1 000 and 3 000 ft.).

While oil sand deposits close to the surface can be strip-mined, in situ thermal recovery methods must be used for deeper deposits. Similarly, experience has shown that only about six per cent of the heavy oil found in place can be extracted by primary recovery methods. To achieve higher recovery rates (25 to 50 per cent are said to be possible), enhanced methods using heat to lower the viscosity of the oil and cause it to move more freely are required.

Of the various enhanced oil recovery methods that have been tried in Alberta's oil sand/heavy oil deposits, steam stimulation (injection) has become accepted as the preferred process in the Athabasca-Wabasca, Cold Lake and Peace River deposits. (In situ combustion is thought to be more suitable for Lloydminster deposits.)

Currently, operations using steam injection generate their steam in natural gas-fired boilers, but the relatively close proximity of subbituminous coal deposits has raised the question as to whether coal might be used instead of natural gas as the fuel for these boilers.

At one time, government policy favoured the use of coal for such purposes. In the mid-1970s, the Alberta government adopted a general policy requiring the use of coal for future thermal power generation, while reserving natural gas for other purposes. This was based on evidence provided by the ERCB showing that using coal instead of natural gas to produce power would result in lower electricity costs and provide greater benefits to the province. At the time, this policy also applied to companies wishing to produce steam for enhanced oil recovery, although it was also noted that the policy should be flexible enough to allow exceptions, if warranted.

In 1981, the ERCB allowed Esso Resources Canada Limited to use natural gas at the latter's heavy oil project near Cold Lake. This decision was made because Esso showed that the economics of natural gas use were more favourable than for coal at that particular scale of operation. Consequently, all projects smaller than Esso's were permitted to use natural gas.

Fuel Options for Enhanced Hydrocarbon Recovery

With this situation as background, Calgary consultants L.A. Smith Consulting & Development Ltd., in collaboration with Hampshire Developments Ltd., undertook a study in 1985 to determine the feasibility of using subbituminous coal or petroleum coke instead of natural gas for steam raising in several oil sand/heavy oil regions of Alberta. The Alberta/Canada Energy Resources Research Fund (through the Alberta Office of Coal Research and Technology) and eight* other clients funded this investigation.

On the basis that projected production levels of oil sands and heavy oil would be realized, the study found that 10.5 to 17.3 megatonnes of subbituminous coal would be needed annually if it were used as fuel for steam raising, including conversion of existing gas-fired steam generators. This quantity is 70 to 110 per cent of current subbituminous coal production, representing a substantially greater expansion of coal mining activities than anticipated from projected increases in thermal power requirements.

The study also showed that natural gas requirements represented only 10 to 12 per cent of current production, but the quantities of coke that would be required exceeded those currently available.

Having demonstrated that steam raising for enhanced oil recovery represented a substantial market for Alberta coal, and knowing that this market could be easily satisfied by Alberta's sizeable coal reserves, the consultants then proceeded to focus on the principal objectives of the study. To determine the capital and operating costs associated with alternative steam-raising fuels, an assessment was made of the technical acceptability of steam-producing systems at various scales of operation, and the delivered fuel costs at several producing locations. This was done for lease crude, electricity, natural gas, petroleum coke and subbituminous coal.

In considering the purchase costs of these fuels, lease crude and electricity were quickly rejected; the former being substantially more expensive than natural gas, and the latter requiring better boiler technology than now exists to satisfy steam requirements.

While it was assumed that delivery of natural gas to the lease boundary was included in the base purchase price, it was necessary to make allowances for the costs of transporting coal and coke. Three modes of coal transportation were evaluated: truck, rail and slurry pipeline. It was assumed that coke would be hauled by rail or truck.

In evaluating the technical acceptability of the various fuel types, the study considered three combustion technologies for their ability to produce 80 per cent quality wet steam at 12 000 kPa (1 740 p.s.i.). They were: gas-fired steam generators, fluidized bed combustion and pulverized coal-fired combustors. Also, the implications of using coal-water mixtures or coal-oil mixtures were considered.

Although the investigators were able to draw upon oil field experience with the first two types of combustors, they noted that pulverized coal-fired boilers have not been used for steam raising in oil field applications. This is primarily because the water-recirculating features of normal boilers do not suit the once-through or single-pass requirements necessary for steam injection into a producing formation. Normally, this results in the production of hot salty water which cannot be recirculated. To enable an evaluation of this type of combustor, a conceptual once-through design was postulated and its costs were estimated.

It was also necessary to consider costs associated with meeting various regulations, including environmental protection rules and guidelines. For example, in considering coal, cost allowances were made for such aspects as in-transit dust control, emissions of sulphur dioxide and nitrogen oxides, and the need for environmentally acceptable methods of ash disposal.

While the economic viability of specific in situ steam projects was beyond the scope of the study, it did address changes to project economics brought about by using fuels other than natural gas. These economic evaluations were made on a before-income-tax basis and were developed by two methods: (1) an approach that calculated the compensatory cost of generated steam, as used by utilities; and (2) a discounted cash flow method. In both cases, the objective was to determine the scale of operation at which any of the alternative fuels could provide steam at a cost equal to (the cross-over or break-even cost) or lower than natural gas. These cost comparisons were developed for five locations within Alberta's oil sand/heavy oil deposits.

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*The other participants were: Alberta Power Limited, Canada Centre for Mineral and Energy Technology, Fording Coal Limited, Luscar Ltd., Pan Canadian Petroleum Limited, Shell Canada Resources Limited, TransAlta Utilities Corporation and Westmin Resources Limited.

Using the utility cost method, the production levels at which coal and coke can provide steam for the same cost as natural gas are:

Steam Cost Cross-Over Points

	Coal				Coke			
	Production Level m^3/day	Barrels/day	Fuel Consumed (kt/yr)	Internal Rate of Return	Production Level m^3/day	Barrels/day	Fuel Consumed (kt/yr)	Internal Rate of Return
Lindbergh	3 902	24 000	730	21.2%	2 765	17 000	317	20.6%
Cold Lake	5 520	35 000	824	21.5%	4 800	30 000	446	19.6%
Peace River	4 800	30 000	1 104	20.4%	>6 400	>40 000	–	–
Central Athabasca	4 800	30 000	1 194	20.5%	1 733	11 000	239	20.6%
Northern Athabasca	6 344	40 000	1 578	20.5%	1 673	10 000	231	20.5%

(Source: *Fuel Options for Enhanced Hydrocarbon Recovery*, L.A. Smith Consulting & Development Ltd., November 1985)

Similar comparisons using the discounted cash flow method and a 10 per cent internal rate of return produced the following results:

Cross-Over Points at 10% Internal Rate of Return

	Coal			Coke		
	Production Level m^3/day	Barrels/day	Fuel Consumed (kt/yr)	Production Level m^3/day	Barrels/day	Fuel Consumed (kt/yr)
Lindbergh	2 140	13 000	400	1 113	7 000	128
Cold Lake	3 274	21 000	532	2 120	13 000	197
Peace River	3 287	21 000	760	3 760	24 000	415
Central Athabasca	3 456	22 000	860	592	3 700	82
Northern Athabasca	3 578	23 000	890	561	3 500	77

(Source: *Fuel Options for Enhanced Hydrocarbon Recovery*, L.A. Smith Consulting & Development Ltd., November 1985)

With interest rates of approximately seven per cent, coal use becomes favourable at all five locations at production levels of approximately 3 200 m^3 a day (20 000 B.P.D.).

Coal Discounted Cash Flow Summary by Location Internal Rates of Return*, %

Production Level m^3/day	Barrels/day	Lindbergh	Cold Lake	Peace River	Central Athabasca	Northern Athabasca
800	5 000	0.2	-11.0	- 9.2	- 8.4	–
1 600	10 000	7.1	- 1.6	- 0.6	0.3	–
2 400	15 000	11.4	2.6	3.8	4.8	–
3 200	20 000	17.3	9.6	9.4	8.0	8.3
4 800	30 000	26.1	18.3	20.4	20.5	15.5
6 400	40 000	33.4	23.5	27.7	28.2	20.7

*Derived from steam generation cash flow differences: coal-fired minus gas-fired.

(Source: *Fuel Options for Enhanced Hydrocarbon Recovery*, L.A. Smith Consulting & Development Ltd., November 1985)

Sensitivity analyses revealed that the economics of using coal or coke were most sensitive to changes in natural gas prices and capital costs.

The investigators noted that transportation costs have a significant effect on the delivered costs of coal. Depending on the coal volume and the haul distance, transportation can account for 13 to 20 per cent of the cost of produced steam.

The principal risks and uncertainties within these economic comparisons were judged to be:

- the level of natural gas prices relative to solid fuel prices;
- the capital costs of solid fuel steam generators; and
- fuel demand levels.

It was recognized that additional research and development is necessary to obtain operating experience in Alberta oil fields for:

- fluidized bed combustion;
- pulverized coal-fired, once-through steam generators having a capacity of approximately 190 GJ/hr.;
- pulverized coal-fired boilers; and
- coal-water fuel mixtures in 190 GJ/hr. steam generators.

Conclusions

The consultants concluded that:

- the projected production and associated demand for steam-raising fuel in each of the major oil sand/heavy oil areas was more than adequate to allow coal or coke to be economically competitive with natural gas; and
- proven reserves of both coal and natural gas are more than adequate to satisfy demands for fuel for 25 years. Coal, in particular, is an underutilized resource, while supplies of coke are limited. This fuel can be supplemented by coal.

Because of the economic sensitivity to the capital costs of solid fuel combustion equipment, it was recommended that any development resulting in lower capital costs and greater flexibility of coal- or coke-fired steam generators would be worthwhile.

Coal Combustion Research Program

The *Fuel Options* report was released one month after the creation of a Joint Industry/Government Coal Combustion Research Program involving the Alberta Office of Coal Research and Technology, the Coal Research Department of the Alberta Research Council, coal mining companies, Canadian boiler manufacturers, electric utility companies and the governments of Canada, Saskatchewan and British Columbia.

This program was established to develop and demonstrate combustion technologies in which western Canadian coals can be used to their best advantage. It was motivated by:

- predictions and indications that thermal coal consumption will increase significantly world-wide; however, the export coal market is highly competitive;
- domestic coal consumption will increase, too, but at a more modest rate;
- coal quality will be an increasingly important criterion for coal selection in both domestic and export markets;
- a co-ordinated coal combustion research and development program could help the coal industry remain abreast of the latest developments in combustion technology, and provide a strategy for testing the suitability of western Canadian coals in these new technologies;
- such a program could provide the organizational structure for evaluating new or improved combustion technologies and their ability to reduce the environmental effects of coal combustion; and
- this approach could identify and research expanded uses for coal and enhance market opportunities in Canada and abroad.

Discussions among the various participants in the program led to agreement on the need for five major research projects. These would be managed by technical committees comprising co-chairmen from industry and government, and involve appropriate representatives from contributing organizations.

The five research projects are:

Coal Combustion Characterization Project;

Technology Awareness Program;

Coal Gasification Study;

Dry Sorbent Injection Study; and

Coal Utilization for Enhanced Oil Recovery Project.

The last project involves several companies* representing the oil and coal industries, who, along with the Alberta Office of Coal Research and Technology and the Alberta Research Council, proposed a four-stage development project as the next step in using coal for enhanced oil recovery.

Coal Use in Enhanced Oil Recovery

In the first phase of the project, begun in April 1987, boiler manufacturers were asked to propose designs for an innovative coal-fired steam generator. They were informed that the objective was to build and demonstrate the accepted design in time for it to be used at Phases 11 to 18 of the Cold Lake heavy oil project operated by Esso Resources Canada Limited. Approval to operate the generator would probably be sought from the Energy Resources Conservation Board in 1991.

In designing the boiler, manufacturers were made aware of the following requirements:

- the fuel would be pulverized coal;
- the boiler feedwater would contain a high total dissolved solids concentration. This would limit steam generation to a single pass and 80 per cent quality;
- the steam generation capacity should be 25 to 50 kg/s (180 000 to 200 000 lbs. an hour) at 1.38 x 10^4 kPa (2 000 p.s.i.);
- a turndown ratio of 4:1 for compatibility with current natural gas applications; and
- modular construction is required to allow truck transportation to field production sites.

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*The initial participants were: Esso Resources Canada Limited, Fording Coal Limited, Luscar Ltd., Obed Mountain Coal Company Limited and TransAlta Utilities Corporation.

Coal-Fired Combustor Concepts

Proposals received from two boiler manufacturers during the summer of 1987 were regarded as approximately equivalent. One, from Combustion Engineering Canada Inc. of Ottawa, proposed to burn coal which had been pulverized so that 70 per cent of the particles will pass a 200 mesh (74 micron) screen. The other proposal, submitted by Struthers-TIW Ltd. of Calgary, involved combustion of micronized coal, a concept new to Alberta. It would burn coal that has been pulverized to allow 90 per cent of the particles to pass a 325 mesh (43 micron) screen.

Because it was felt that both combustion systems looked promising, and each had its own strong points, a two-track development program was adopted by the project technical committee. It was decided that the companies represented on the committee as a whole would support development of the Combustion Engineering technology, while Esso Resources Canada Limited would fund development of the Struthers-TIW system.

Consequently, additional phases of the project have been identified, including:

- development of an optimal boiler design;
- preparation of a design for a pilot-scale demonstration combustor;
- development of a suitable emission control technology;
- approval of the design and permission from the ERCB to proceed with a demonstration; and
- construction and operation of a pilot-scale combustor.

If completed, it is anticipated this development program would cost over $10 million. The potential benefits, however, are estimated to be several times this amount in terms of domestic coal sales and lower steam production costs.

For these reasons, coal companies, oil firms and other interested parties are being invited to participate in the subsequent project phases to obtain access to the technology. Given the anticipated costs of the project, it is doubtful whether it will proceed without substantial participation from the oil and coal industries.

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